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CONFORMAL TIME DOMAIN FINITE DIFFERENCE METHOD OF SOLVING ELECTROMAGNETIC WAVE SCATTERING

Final Report

by

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The objective of this research project is to develop simple solution techniques for time domain differential equations, with conforming boundaries, air-ground interfaces and proper absorbing boundary conditions. The accomplishments in that effort is represented by numerous Ph.D dissertations and journal publications.

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I. Introduction

Time Domain Finite Difference Method was a novelty in field computations, because it had the potential to solve many hitherto unsolvable problems, but it required so much memory that it was beyond the available resources for many research laboratories. But, that limitation is no longer there. Because of the reasonable availability of the Cray machines. It is therefore essential to improve the time domain computational method so that it can be applied to practical problems. This report presents the accomplishments of the work, supported by the contract, in advancing the art of time domain computation both in theory and practice.

II. Time Domain Finite Difference (TDFD)

The time domain finite difference method as presented by Yee*, uses the leap-frog method to solve scattering problems is not boundary conforming, i.e., it uses steps to approximate curved surfaces. Besides the inaccuracy incurred as a result of the step approximation, the method is not satisfying as a modeling technique of fine structures for many microwave components. It is also rather common that the time domain technique of Yee's is applied with only a monochromatic wave as excitation.

A scrutiny of many of the prior computations has led us to believe that the time domain method needs some honest clarification before large scale applications are possible. One issue is the conforming boundary, and the other is the absorbing boundary condition. Both problems are not emphasized by those who promote the time domain techniques. They seem to be irritations but not road blocks to the applications of the method. Yet, without putting these two issues to rest, it is almost impossible to rely on the time domain method for dependable results. That is why the objective of this project is to emphasize the development of the time domain finite element method and the local absorbing boundary conditions.

III. Time Domain Finite Element Method

To relax the restrictions of the finite difference method, we use an interpolation technique to find the field inside an element from the surrounding nodal points. The differentiation of the function is analytically found from the interpolation function. Since the interpolation is not limited to regular mesh, we are able to generalize the method to conforming meshes. This technique is fully developed during the course of this project and resulted in a Ph.D dissertation and several conference presentations and one journal publication.

IV. Time Domain Finite Element Method

The absorbing boundary condition is a necessary part of solving radiation problems in any differential equation approach. However, it has not been considered a serious problem by most practitioners. Ad hoc methods have been used, although many interesting papers have been published in that subject. The reason is, in most scattering problems, those ad hoc method seem to give reasonable results.

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*Yee, K. S. "Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equations In Isotropic Media," *IEEE Trans. Ant. and Propagation*, Vol. AP-14, pp. 302-307, 1966.

The situation is quite different, however, when one applies the time domain method to scattering by buried targets or to modeling of microwave components. The emphasis on that topic in this project has also resulted in one Ph.D dissertation and several conference and journal papers.

V. Ph.D Dissertations

The Ph.D dissertations supported in whole or in part by this project are:

1. "Scattering of Electromagnetic Waves by Buried or Partly Buried Inhomogeneous Bodies of Revolution," by Henry Sing-Horng Chang.
2. "Time Domain Computation of Electromagnetic Wave Scattering by the Method of Conforming Boundary Elements," by Andreas Costa Cangellaris.
3. "Numerical Modeling of Two-Dimensional Time Domain Electromagnetic Scattering by Underground Inhomogeneities," by Chung Chi Lin.

Abstract of the above dissertations are attached.

VI. Papers and Conference Presentations

The following are journal papers and conference presentations resulted from this contract.

Journal Papers:

1. "Scattering of Electromagnetic Waves by Buried and Partly Buried Bodies of Revolution," (with H. Chang), *IEEE Trans. on Geosciences and Remote Sensing*, Vol. GE-23, No. 4, pp. 596 – 605, July 1975.
2. "Unimoment Method for Electromagnetic Wave Scattering," *Journal of Electromagnetic Waves and Applications*, Vol. 1, No. 4, pp. 321 – 342, 1987.
3. "Point-Matched Time Domain Finite Element Methods for Electromagnetic Radiation and Scattering," *IEEE Trans. on Antennas and Propagation*, September 1987.

Conference Presentations:

1. "Time Domain Absorbing Boundary Condition in Lossy Media," *IEEE AP-S/URSI Symposium Digest*, pp. 7 – 10, Boston, MA, June 1984.
2. "Finite Element Methods in Electromagnetic Computations," *URSI/USNC, Conference Digest*, p. 227, Philadelphia, June 1986.
3. "Time Domain Computation of Electromagnetic Wave Scattering by 3-Dimensional Targets," *URSI International Symposium on Electromagnetic Theory*, p. 80, Budapest, Hungary, August 1986.

Time-Domain Computation of Electromagnetic Wave Scattering by the Method of Conforming Boundary Elements

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ABSTRACT

The method of conforming boundary elements is developed and applied for the numerical computation of transient electromagnetic wave scattering from composite two and three-dimensional structures in free space illuminated by an impulsive wave.

The transient scattering problem is formulated as an initial-boundary-value problem governed by Maxwell's differential equations and is numerically solved by means of a finite-element time-domain method. Boundary elements are introduced to conform the desirable conducting geometries and dielectric interfaces. Additional numerical conditions are implemented for satisfying the radiation condition for the scattered field on an artificial boundary that is used for the truncation of the finite-element region. The convergence and the stability of the numerical method, as well as the various types of errors introduced by the numerical discretization, are investigated. Stable numerical models for treating the field singularities at the vicinity of edges and corners are also discussed.

Computations are carried out for scattering by two-dimensional, perfectly conducting cylinders of arbitrary cross-section illuminated by a plane-wave Gaussian pulse at normal incidence. The results are in good agreement with those obtained from a time-domain integral equation approach. Scattering by dielectric cylinders is also computed and the focusing effect of the dielectrics is illustrated. Finally, the method is applied for the numerical computation of scattering by finite conducting cylindrical structures with constant cross-section. The structure can be more complex by adding conducting fins or wires to it. Available experimental results provide us with a further check of the validity of the method. Because of its demonstrated accuracy, efficiency and versatility, the method will be a powerful tool in the study of electromagnetic scattering and penetration of large arbitrary shaped composite targets.

Scattering of Electromagnetic Waves by
Buried or Partly Buried Inhomogeneous Bodies of Revolution

Henry Shing-Horng Chang

Ph.D

Department of
Electrical Engineering
and Computer Sciences

Kenneth K. Mei
Chairman of Committee

ABSTRACT

The phenomenon of the electromagnetic scattering by a finite object located near or on a planar interface, which separates the dielectric medium above (i.e. air) and the homogeneous lossy ground below, renders no simple analytical solution. Even for the simplest configuration where the object is a conducting sphere buried far below the ground, considerable amount of computational work is necessary. In an effort to make accurate predictions on the electromagnetic fields induced by dielectric bodies buried near a lossy ground, an effective numerical technique via the unimoment method is developed.

In the scattering analysis, the unimoment method decouples the interaction between the scatterer and the surrounding environment, and replaces it by a set of simpler continuity conditions on the "unimoment surface". In applying this technique to the two-medium scatterings by buried or partly buried inhomogeneous dielectric bodies, the space is divided into the interior and exterior regions by a closed mathematical surface--the unimoment surface, with the scatterer completely situated in the interior region. The exterior

expansion modes are expressed in terms of the generalized Sommerfeld's integrals which satisfy the boundary conditions on the air-ground interface. The field solution interior to the unimoment sphere is expanded by a set of numerical basis functions. Each basis function is generated by the finite element method with specific boundary conditions applied on the unimoment sphere.

The interior basis functions and the exterior modal fields are coupled together via the minimum mean square error scheme on the unimoment sphere to determine the scattering coefficients. Once these coefficients have been found, the various scattered field quantities such as the field patterns, and scattering cross sections can be obtained. Selected case studies of buried and partly buried scattering test results are presented to demonstrate the validity of the program and to lay a foundation for the future study and analysis.

Numerical Modeling of Two-Dimensional Time Domain Electromagnetic Scattering by Underground Inhomogeneities

by

Chung-Chi Lin

ABSTRACT

The present study examines the feasibility of the active electromagnetic remote sensing of elongated subsurface structures such as hidden archeological ruins, tunnels, conduits and underground waterflows. The theoretical investigation of the scattering from a buried target in the homogeneous earth is performed in the presence of an impulsive incident wave excitation.

The initial-boundary-value problem formulation, by Maxwell's differential equations, of two-dimensional scattering is numerically solved by means of the point-matched (collocation) finite element method in the time domain. The greatest difficulty encountered in this modeling process is in satisfying the radiation condition of the scattered field at the boundary of the finite element region. An extension of the free space absorbing boundary condition allowed to account for the lossy character of the earth and the presence of the air-earth interface, achieving a better absorbtion of the outward travelling wave.

Computations are carried out for two different types of excitations: a plane wave at the normal incidence and a line source above the ground. The time histories of the scattered fields along the ground surface are presented and analysed through a parametric study. Those results demonstrate the definite advantage of the fast transient sensing method over the use of the more conventional sinusoidal excitation. In particular, the time delay of the specular reflection from

the target with respect to the ground response facilitates the identification of the inhomogeneity's presence.

Kenneth K. Mei

Kenneth K. Mei

Committee Chairman

May 14, 1985